ALTERNATIVE MULTIPLE-ACCESS TECHNIQUES FOR MOBILE SATELLITE SYSTEMS

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ABSTRACT

This paper discusses the use of Code Division Multiple Access (CDMA) to satisfy the diverse requirements of a generic (land, maritime, aeronautical) MSS network design. Comparisons between CDMA and Frequency Division Multiple Access (FDMA) show that a CDMA network design can support significantly more voice channel allocations than FDMA when relatively simple CDMA correlation receivers are employed, provided that there is sufficient space segment EIRP. The use of more advanced CDMA receivers can improve the spectral and power efficiency. Although the use of CDMA may not gain immediate and widespread support in the international MSS community, provision for the use of CDMA for a domestic system in the U. S., and possibly for a regional system throughout North America, is likely.

I. INTRODUCTION

This paper discusses a limited number of technical and practical aspects of alternative multiple-access techniques that may be used in MSS systems. There are many network architectures and associated multiple-access techniques that can support the requirements of MSS systems. There are also many technical and non-technical factors that must be considered and this makes the choice of a single, global MSS network design that simultaneously satisfies the needs and/or desires of the predominant factions and factors a difficult and time consuming process. **Figure 1** depicts many of the conflicting issues and requirements.

II. ALTERNATIVE MULTIPLE-ACCESS TECHNIQUES

MSS systems are intended to provide low data rate (i.e., less than 19.2 kbps) communications to a large number of geographically-dispersed low-duty-cycle mobile users. The multiple access of the space segment bandwidth, power, and time by a large number of low-duty-cycle users can be accomplished by FDMA, TDMA, CDMA, and/or any combination of these techniques. The use of pure TDMA alone will not be considered because of the requirements on the mobile terminals for peak power, G/T, and network synchronization.
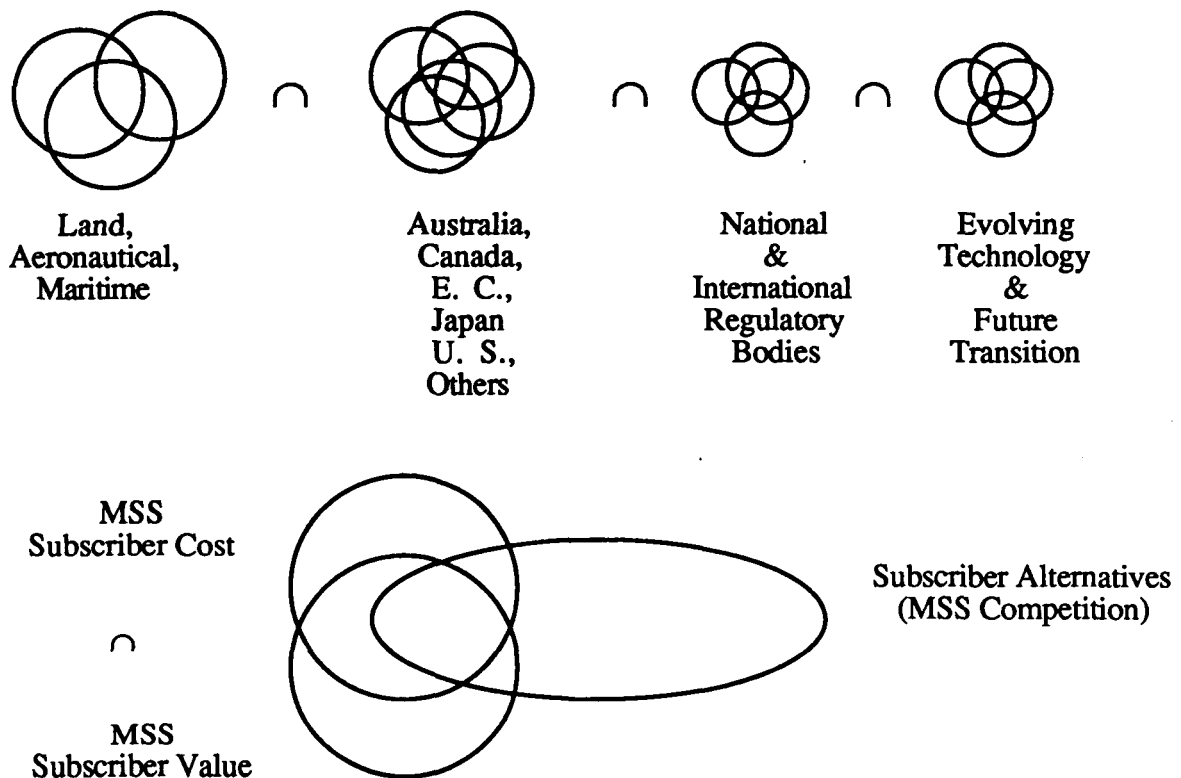
| Land, Aeronautical, Maritime | Australia, Canada, E. C., Japan U. S., Others | National & International Regulatory Bodies | Evolving Technology & Future Transition |

MSS Subscriber Cost

∩

MSS Subscriber Value

Subscriber Alternatives (MSS Competition)

Figure 1. Depiction of "Golden Intersection" for Global MSS Network Standardization.

A. Assumed First-Generation MSS Space Segment

Figure 2 shows the MSS system architecture and associated space segment (assuming CDMA operation). Frequency reuse of the L-Band spectrum is provided by spatial separation of B L-Band coverage beams. The use of analog-repeater ("bent-pipe") type space segment is assumed with fixed L-Band coverage beams. Each fixed L-Band coverage beam maps to a unique, non-overlapping portion of SHF or EHF spectrum. In addition, for the CDMA technique, the reuse of polarization (i.e., simultaneous use of both left-hand and right-hand polarizations) is assumed.

B. Practical Issues Regarding the Alternative MA Techniques

The range of traffic characteristics and requirements that can be efficiently supported by a given network architecture and multiple access technique is an important issue. For MSS, the use of FDMA, TDMA, or CDMA can satisfy many requirements. **Figure 3** depicts the range of MSS requirements and applications that can be satisfied with FDMA, TDMA, and CDMA. A viable network architecture for MSS will provide some segment of the bandwidth for FDMA due to its use in existing systems. However, because the use of CDMA can result in significantly more capacity than FDMA, as shown later, it is therefore desirable to provide as much bandwidth for CDMA as possible, assuming sufficient EIRP can be provided.

The usage charges and billing requirements differ for FDMA and CDMA. These arrangements are fairly simple with FDMA. Any service provider can request a channel on demand from the authorized system operator. The service provider would pass the cost of the usage to the end subscriber. With CDMA the usage charges must be based on the percentage of capacity used by a particular type of accessing user.
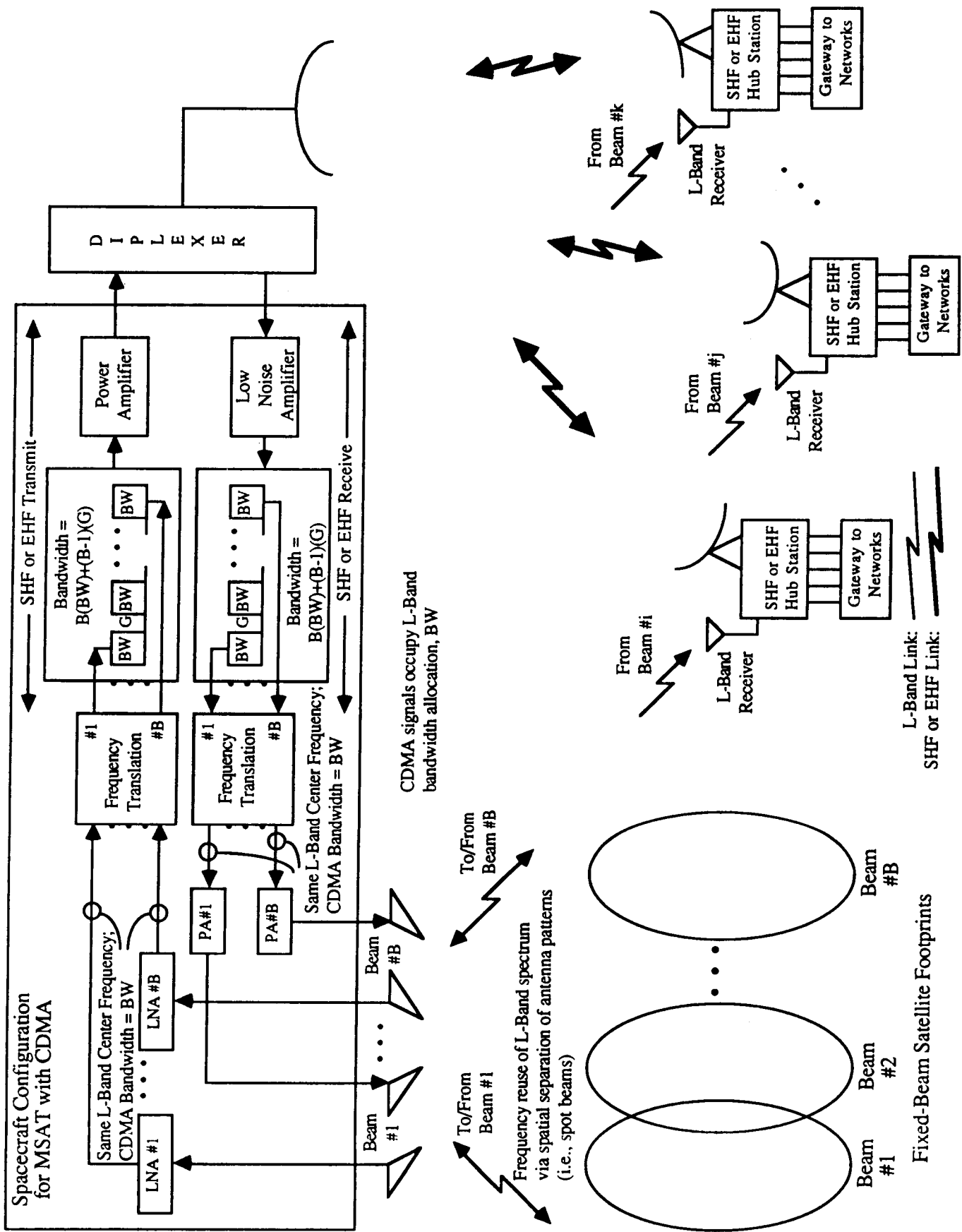
Spacecraft Configuration for MSAT with CDMA

D
I
P
L
E
X
E
R

Power Amplifier

Low Noise Amplifier

SHF or EHF Transmit

Bandwidth = B(BW)+(B-1)(G)

BW

BW | G | BW

Bandwidth = B(BW)+(B-1)(G)

BW

BW | G | BW

SHF or EHF Receive

#1

Frequency Translation

#B

#1

Frequency Translation

#B

Same L-Band Center Frequency; CDMA Bandwidth = BW

CDMA signals occupy L-Band bandwidth allocation, BW

Same L-Band Center Frequency; CDMA Bandwidth = BW

LNA #1

LNA #B

PA#1

PA#B

Beam #1

Beam #B

To/From Beam #1

To/From Beam #B

Frequency reuse of L-Band spectrum via spatial separation of antenna patterns (i.e., spot beams)

From Beam #i

L-Band Receiver

SHF or EHF Hub Station

Gateway to Networks

From Beam #j

L-Band Receiver

SHF or EHF Hub Station

Gateway to Networks

From Beam #k

L-Band Receiver

SHF or EHF Hub Station

Gateway to Networks

L-Band Link:

SHF or EHF Link:

Beam #1

Beam #2

Beam #B

Fixed-Beam Satellite Footprints

Figure 2. System Level Diagram of Mobile Satellite System.

CDMA with
Simple Transceivers
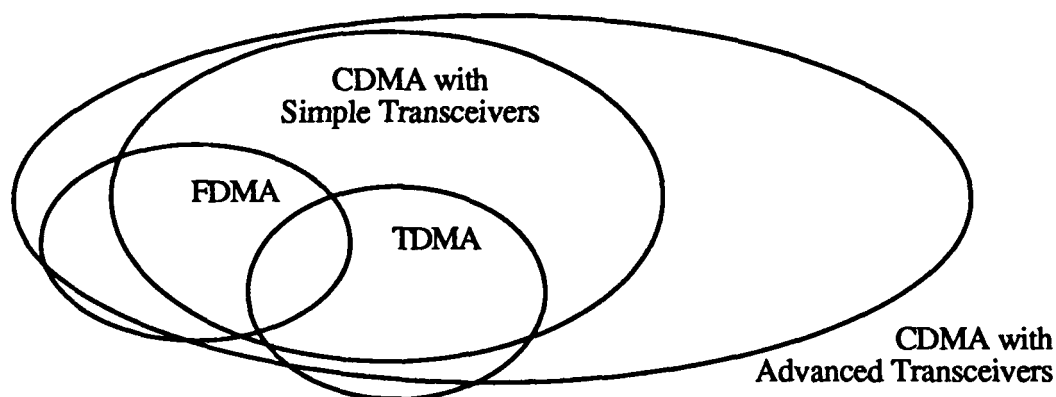
FDMA

TDMA

CDMA with
Advanced Transceivers

Figure 3. MSS Applications & Requirements Comparison of FDMA, TDMA, & CDMA.

The use of a standard suite of CDMA protocols can be conceived to support specified user service classes while facilitating the management and billing logistics. In addition, the coexistence of many service providers in the same spread spectrum bandwidth implies some level of standardization of the CDMA waveforms and multiple access protocols. The management and authorization of various CDMA waveforms and protocols must be addressed by the system operator. The most lucrative future market segment may require specialized CDMA waveforms and associated MA protocols. The effect on the other users of the CDMA system by the possible non-homogeneity of numerous CDMA waveforms must again be translated to an equivalent "percentage of system capacity used" to determine the service charges.

III. SYSTEM CAPACITY: CDMA versus FDMA

In the section, the capacity of a single, generic spot beam is presented for the case of a 7 MHz bandwidth allocation and the all voice traffic scenario. The overall system capacity would then be determined by accounting for the overall frequency reuse factor that can be provided for a given system design. In the case of CDMA, multiplication by the number of beams would provide the overall capacity. In the case of FDMA, the division of the bandwidth among adjacent beams and overall reuse of frequencies for non-adjacent beams must be accounted.
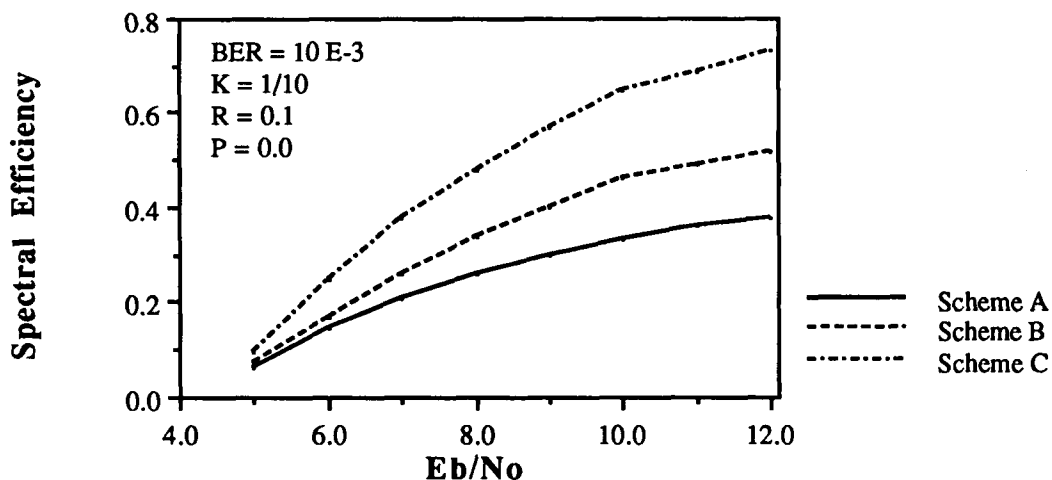
A. CDMA Capacity

The spectral efficiency of CDMA is defined as $K_{max}R_b/W$, where K_{max} is the maximum number of instantaneously accessing signals that can be supported at a given bit error rate, R_b is the information data rate of each signal in bits per second, and W is the total bandwidth in Hertz. The spectral efficiency as a function of the Eb/No in the forward (hub-to-mobile) and return (mobile-to-hub) directions is shown shown for several CDMA transceiver schemes, labelled A, B, C, D, and E. The simplest of these schemes (Scheme A) is a conventional correlation receiver with a rate 1/3 constraint length 9 convolutional code and hard-decision decoding. Scheme B employs optimal FEC coding as predicted by sum cut-off rate calculations. The remaining schemes make use of the knowledge of the specifics of the other user interference at the receiver to varying extents. This increases receiver complexity, but it results in significantly improved spectral **and** power efficiency.
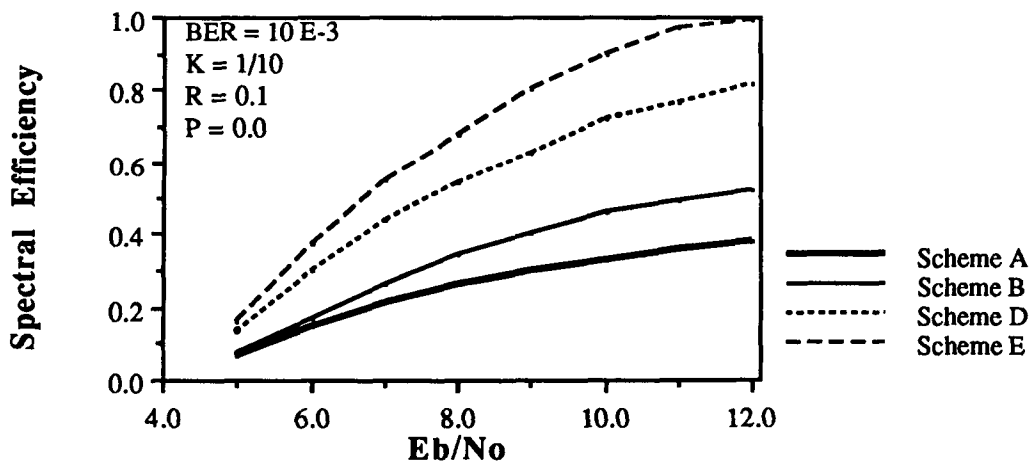
The results shown are based on the following assumptions: a) a bit error rate of 1 x 10 E-3, b) a polarization reuse factor, P of zero (later a factor of 50% will be used), c) a Rician

channel parameter K of 1/10, d) use of the Gaussian approximation, e) uniform distribution of mobiles over a generic spot beam coverage zone, and f) a percentage of users, R = 0.1, in the overlapping region between the generic beam of interest and all other adjacent spots beams. The downlink L-band EIRP for these overlapping regions is assumed to be exactly 3 dB less than the center of the generic beam. The implication of this assumption is that additional downlink L-band EIRP must be allocated to the mobiles in the overlapping region maintain the same Eb/No as mobiles at beam center. Thus, the level of interference added to all users of the beam by each mobile in the overlapping region in the forward direction will be higher than the level of interference added to all users of the beam by each mobile in the center region of the beam. In addition, mobile uplink transmissions add equal interference levels to all beams covering the overlapping region.

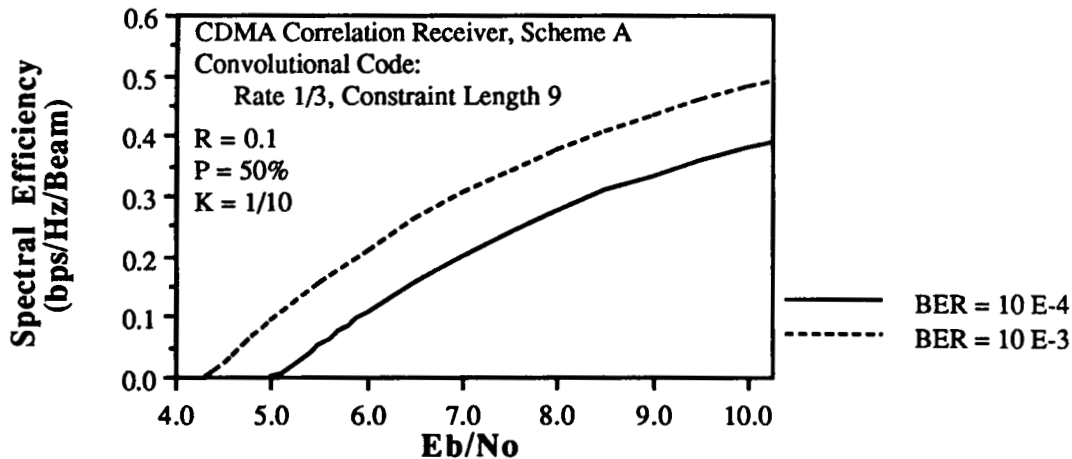## Spectral Efficiency of CDMA vs. Eb/No (Forward Link)

Spectral Efficiency of CDMA vs. Eb/No (Return Link)

The resulting spectral efficiency versus Eb/No for the simplest of the CDMA transceivers is shown next, where a 50% increase in spectral efficiency to account for the polarization reuse has been included. At an Eb/No of 10 dB the resulting spectral efficiency is about 0.50. To achieve this level of spectral efficiency with a 3 dB margin for all users would require a link budget that provides an additional 3 dB of Eb/No per user signal, i.e. 13 dB would be required.

Spectral Efficiency per Spot Beam (CDMA)

Some comparisons can be made assuming a spectral efficiency of 0.50 per spot beam for CDMA, which would require sufficient spacecraft EIRP to support an Eb/No of about 10 dB for all users with CDMA, assuming a BER is 1x10 E-3 (no margin included). As previously mentioned, improved power and spectral efficiency can be provided. Assuming a voice activity factor of 0.4, the *effective* spectral efficiency per spot beam for the all-voice-traffic scenario would be **1.25 bps/Hz/spot beam**. With a 7 MHz bandwidth allocation, **1822 voice channels** could be supported assuming 4.8 kbps digital voice. Assuming a voice activity factor of 0.33 and a spectral efficiency per spot beam of 0.75, the *effective* spectral efficiency per spot beam for the all-voice-traffic scenario would be **2.25 bps/Hz/spot beam**. Under this assumption, with a 7 MHz bandwidth allocation, **3281 voice channels** could be supported assuming 4.8 kbps digital voice.

B. FDMA Capacity

It is assumed that sufficient spacecraft EIRP is available to provide an Eb/No of 10 dB for all users with FDMA and that the modulation and coding technique provides a BER of 1x10 E-3 (no margin included). With an FDMA **channelization of 5 kHz** and a 7 MHz bandwidth allocation, the resulting maximum number of voice channels per spot beam would be **1400**. With an FDMA **channelization of 7.5 kHz** and a 7 MHz bandwidth allocation, the resulting maximum number of voice channels per spot beam would be **933**.

IV. CONCLUSION

Both power and spectral efficiency are important parameters in the comparison of CDMA and FDMA. Even with simple, conventional CDMA correlation receivers, the use of CDMA can provide significantly higher capacity than FDMA for the all-voice-traffic scenario. This higher capacity can be achieved provided there is sufficient space segment EIRP to achieve good spectral efficiency. The requirements on space segment EIRP can be relaxed by the use of more advanced CDMA transceivers, which can provide significant improvements in power and spectral efficiency. To achieve the maximum efficiency with CDMA, a minimum contiguous bandwidth allocation is required to support a given maximum user data rate. The loss in efficiency that may result from too narrow a bandwidth allocation will be a function of the ratio of the bandwidth allocation for CDMA operation to the maximum user data rate to be supported. The efficiency decreases gracefully as the aforementioned ratio decreases and depends on the specific CDMA transceiver structures and code parameters.